PB-232 544

THE EFFECT OF CARBON MONOXIDE ON TIME PERCEPTION

MEDICAL COLLEGE OF WISCONSIN

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY
COORDINATING RESEARCH COUNCIL, INCORPORATED

JANUARY 1973

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-650/1-74-005	2. PB 232 544
4. TITLE AND SUBTITLE: The Effect of Carbon Monoxide on Time Perception	5. REPORT DATE: January 1973 6. PERFORMING ORGANIZATION CODE:
7. AUTHOR(S): Richard D. Stewart, M.D., M.P.H. Jack E. Peterson, PH.D. Paul E. Newton, M.S. Michael J. Hosko, Ph.D.	8. PERFORMING ORGANIZATION REPORT NO.: MCOW-ENVM-CO-72-2
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Department of Environmental Medicine The Medical College of Wisconsin 8700 West Wisconsin Avenue Milwaukee, Wisconsin 53226	10. PROGRAM ELEMENT NO.: 1AA005 11. CONTRACT/GRANT NO.: CRC APRAC CAPM 3-68 EPA Contract No. CPA 70-7
12. SPONSORING AGENCY NAME AND ADDRESS: Cordinating Research Council, Inc. and the U. S. Environmental Protection Agency	13. TYPE OF REPORT AND PERIOD COVERED: Final 14. SPONSORING AGENCY CODE:
15. SUPPLEMENTARY NOTES	

16. ABSTRACT

Twenty-seven healthy, adult male and femlae volunteers were exposed to carbon monoxide at concentrations of < 2, 50, 100, 200 and 500 ppm for periods up to 4 1/2 hours for the purpose of determining the effect of gas upon time perception. These exposures, which resulted in a range of carboxyhemoglobin saturations up to 20%, produced no impairment in the ability of the subject to perform the Beard-Wertheim Time Discrimination Test, to estimate ten or thirty second intervals, or to perform the Marquette Time Estimation Test.

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
carbon monoxide carboxyhemoglobin time perception	carbon monoxide carboxyhemoglobin time perception	

18. DISTRIBUTION STATEMENT: general - unlimited	19. SECURITY CLASS *(This Report)*: Unclassified	21. NO. OF PAGES: 54
	20. SECURITY CLASS *(This page)*: Unclassified	22. PRICE: $3.75

EPA Form 2220-1 (9-73)

THE EFFECT OF CARBON MONOXIDE ON TIME PERCEPTION

By

Richard D. Stewart, M. D., M. P. H.

Paul E. Newton, M. S.

Michael J. Hosko, Ph. D.

Jack E. Peterson, Ph. D.

REPORT NO.: CRC APRAC CAPM-3-68 MCOW-ENVM-CO-72-2

From the Department of Environmental Medicine, The Medical College of Wisconsin, 8700 West Wisconsin Avenue, Milwaukee, Wisconsin, 53226.

Supported by Contract CRC-APRAC, Project No. CAPM-3-68, from the Coordinating Research Council, Inc., and the Environmental Protection Agency.

THE EFFECT OF CARBON MONOXIDE ON TIME PERCEPTION

By

Richard D. Stewart, M. D., M. P. H.

Paul E. Newton, M. S.

Michael J. Hosko, Ph. D.

Jack E. Peterson, Ph. D.

REPORT NO.: CRC APRAC CAPM-3-68 MCOW-ENVM-CO-72-2

From the Department of Environmental Medicine, The Medical College of Wisconsin, 8700 West Wisconsin Avenue, Milwaukee, Wisconsin, 53226.

Supported by Contract CRC-APRAC, Project No. CAPM-3-68, from the Coordinating Research Council, Inc., and the Environmental Protection Agency.

The first untoward effect of carbon monoxide (CO) upon healthy man is reported to be a gross impairment in his ability to distinguish between short intervals of time and to estimate 30-second intervals [1,2]. Alarmingly, these decrements in time perception are reported to be produced by exposures to CO at concentrations as low as 50 parts per million (ppm) for 90 minutes, exposures which are currently acceptable in American industry [3], commonly encountered by urban populations [4,5], and much lower than those experienced by the average adult smoking one pack of cigarettes per day [4,6].

The implications of these CO induced decrements were judged to be of such critical importance that two independent research groups conducted similar, though not identical, time perception experiments in an attempt to corroborate the observations of the original investigators, Beard and Wertheim. Neither independent research group was able to do so [7,8,9]. Meanwhile, major review articles dealing with the toxic effects of CO upon man listed the time perception impairment as an early untoward effect of CO exposure [5,10,11,12]. The issue became more confused when Dr. Beard announced that he was unable to reproduce his original findings [13].

In an effort to gain additional information as to the precise effect of CO upon human time perception, a comprehensive investigation was undertaken which included a series of time tests performed under conditions identical to those reported by Beard and Wertheim in their original work. This investigation is the subject of this report.

EXPERIMENTAL METHOD

The performance of these time perception studies required that healthy volunteers be exposed to CO. This was done with strict adherence to the ethical and technical requirements for human inhalation experimentation previously detailed [14].

Exposure Chamber:

The CO exposures were carried out in the controlled environmental chamber located at the Department of Environmental Medicine, The Medical College of Wisconsin [7]. The chamber, a room measuring 20 x 20 x 8 feet, provided accurate control of temperature (72 $\pm$ 2° F) and relative humidity (40 $\pm$ 5% RH) for all exposures. This chamber featured pleasant lighting, comfortable chairs, study tables, a restroom facility and an audiometric booth (Industrial Acoustics Co., Model 401). The subjects were under continuous visual surveillance by medical personnel while in the chamber and, in addition, their activities were visually monitored and periodically video taped by closed circuit television.

Exposure Chamber Atmosphere:

Carbon monoxide was continuously metered into the chamber's incoming air supply from a compressed gas cylinder in the adjacent command laboratory. The CO used was a chemically pure grade with a minimum purity of 99.5%.

Chamber CO concentration gradients when operating at 100 ppm and with subjects stationary, were found to be less than 2 ppm, except inside of the restroom facility and immediately in front of the entrance door where the concentration was lower by 3 - 5 ppm. Studies showed the audiometric booth's circulation fan kept the interior of the booth at the chamber concentration.

The concentration of CO in the chamber atmosphere was continuously recorded by an infrared spectrophotometer equipped with a 10-meter path-length gas cell which was continuously flushed with air drawn from the chamber through $\frac{1}{4}$" diameter polyethylene tubing. A MSA CO meter and alarm, Model 701, provided a second independent means of continuously monitoring chamber concentration. The chamber atmosphere was also sequentially sampled by a gas chromatograph (GC) equipped with a helium ionization detector.

All three independent methods of monitoring CO concentration during an exposure were calibrated from within the chamber with a series of standards prepared in 30-liter saran bags. Prior to each exposure and every hour during each chamber exposure the series of CO standards was run.

Subjects:

During the period from February 1970 to August 1971, 27 healthy graduate students and Medical School faculty, 23 males and 4 females, ranging in age from 22 to 43 years, served as volunteer subjects for the exposure studies. Three of the subjects were smokers, and they agreed to abstain from

smoking for the duration of the study; pre-exposure carboxyhemoglobin (COHb) attested to this agreement. Prior to and after completion of the study, each subject was given a comprehensive medical examination, which included a complete history and physical examination, a 12-lead EKG and a standard EEG.

Carboxyhemoglobin Determination:

Venous blood samples for COHb determination were obtained from each subject 30 minutes prior to exposure and evey hour during exposure so that time perception test results could be correlated to blood COHb saturations. At the time of blood sampling a subject would stick his arm through an arm-port in the chamber wall into the adjacent laboratory so that the venipuncture could be performed in an uncontaminated atmosphere.

Five milliliter aliquots of venous blood were collected in Vacutainer tubes containing ethylenediaminetetraacetic acid. The blood was immediately analyzed by two methods [4, 7]. The first method determined the hemoglobin concentration and the COHb percentage directly using a CO-Oximeter (Instrumentation Laboratories, Inc.). The second analytical method consisted of measuring the CO liberated from the COHb moiety, using the gas chromatograph equipped with a helium ionization detector.

Testing Procedure:

The study consisted of double-blind exposures conducted in a random order to < 2, 50, 100, 200 and 500 ppm CO for periods of time up to $4\frac{1}{2}$ hours.

Exposures were designed so that the maximum COHb saturation reached would not exceed 20%. A chronological listing of these exposures along with the mean and standard deviation of the CO concentration for each is presented in Table I.

Three tests of time perception were used in this study. The time discrimination test along with the 10- and 30-second estimations were the two tests originally administered by Beard and Wertheim to subjects isolated in an audiometric booth [1,2]. The third test, the Marquette Time Estimation Test, was previously administered by Stewart, et al, to subjects in a group setting to evaluate the effect of CO upon time sense [7]. The tests were administered each hour during exposure in the following order: 10- and 30-second estimation, the Marquette Time Estimation Test, and the Beard-Wertheim Time Discrimination Test. The complete protocol used is printed in the first CRC report [15].

In order to investigate the difference resulting from testing conducted in an isolated or group setting, nine subjects were tested in an audiometric booth, isolated in the environmental chamber, and in a group setting in the environmental chamber. When the time perception tests were performed in a group setting, each subject was seated in a chair equally spaced along one side of a table spanning two sides of the chamber. Each performed his test in absolute silence while looking straight ahead.

The subjects were arbitrarily divided into five groups for testing purposes. Prior to commencing the study, each group of subjects had one

training session. During this session the subjects were seated in the exposure chamber and given the series of tests in the exact order and with the same instructions as they would be given during an actual exposure. Previous experience with the battery of time tests indicated that there was no learning effect once the subject became familiar with the mechanics of testing. The "learning" curves for the five groups affirm the validity of this prior observation[15].

Marquette Time Estimation Test:

A detailed description of this test has been presented previously[7,15]. It consisted of a series of nine tone stimuli followed by a series of nine light stimuli, the duration of each of which the subject was required to estimate. Each series contained stimuli of approximately 1, 3, or 5 seconds duration, which were presented in a random order with three stimuli at each time interval. At termination of the stimulus, the subject immediately depressed a push-button switch for that interval of time he estimated to be equal in duration to the original auditory or light stimulus. This provided a measurement of his reaction time and of his ability to estimate the duration of the stimulus. It required seven minutes to perform this test.

Ten and Thirty Second Time Estimation:

To perform these time estimation tests, each subject depressed the pushbutton described above for an interval he estimated to be 10 seconds;

this was repeated twice. The 30-second estimation test was performed in the same way and was repeated twice.

Beard-Wertheim Time Discrimination Test:

The time discrimination test was designed to test a subject's ability to discriminate differences in duration of two short intervals of time. The test was composed of three sequences with 30 seconds rest between each sequence. Each sequence consisted of 25 pairs of tones as described by Beard and Wertheim [1,2]. The first tone was always one second in duration and was followed 1.5 seconds later by a randomly selected second tone of identical, slightly longer or slightly shorter duration. The duration of the second tone for each sequence is listed in Table II.

Listening through his individual earphone to the taped sequence (Precision Instruments Model 6100 tape recorder), the subject decided at termination of the second tone whether it was the same, longer, or shorter than the duration of the first tone. He signaled his response by depressing one of three push-button switches on a mini-box which were labeled "longer," "same," and "shorter."

The set of three test sequences (75 pairs of tones) took approximately 15 minutes to perform.

Data Analysis:

Group F and t-tests were performed to compare baseline time perception data (< 2 ppm CO) to performance data collected during exposure

(> 2 ppm CO). Then paired t-tests were used to search for individual responses to CO exposure. To further investigate the difference between the means of the baseline and exposure data, 95% confidence limits of this difference were calculated. Regression analysis of the test scores with COHb saturations were also done.

In an attempt to minimize the effect of spurious data, the score of any test less than or greater than the mean $\pm$ 3 standard deviations was considered to be spurious and eliminated from further data analysis. The data eliminated and the corresponding COHb saturations can be found in Appendix F of reference 15. It can be seen that these extreme values were random and not a function of COHb saturation.

For the time discrimination test, the number of correct responses in each sequence of 25 stimuli along with the associated COHb saturation composed the bivariate sample population. For the 10- and 30-second time estimations, each estimate and the associated COHb saturation composed the bivariate sample population. And for the Marquette Time Estimation Test, each response for a stimuli with its associated COHb saturation composed the bivariate sample population.

RESULTS

All of the data which were collected during this investigation are available for review in reference 15. The space limitations of this report

only allows the inclusion of those data most pertinent to the discussion.

The Effect of CO on the Beard-Wertheim Time Discrimination Test:

The ability of the subjects to perform this time perception test at various COHb saturations in the three test settings is summarized in Tables III, IV, V and VI. A group F test and t-test showed that the ability to perform this test in the three settings was not altered by CO exposures resulting in COHb saturations ranging from 0.4% to 20%. Regression analysis yielded maximum correlation coefficients of -0.51, -0.097, and 0.308 for the group, the isolated, and the booth settings, respectively.

Should an elevated COHb be responsible for a minute decrement in time discrimination not detected by the statistical methods employed, the absolute value of the difference in group means for the number of correct responses for each sequence of 25 stimuli can be calculated with 95% confidence to be less than .44 (1.8%), 1.50 (6.8%), and 1.05 (4.3%) for the group, isolated and booth settings, respectively.

A paired t-test was employed to compare each subject's mean baseline score with his mean score following CO exposure (Table VII). For the group and isolated settings there was no significant difference. In the booth setting, however, seven of the nine subjects had "statistical" decrements in their performance when exposed to CO with an average decrement of 0.74 out of 25 (2.9%), significant at the 95% confidence level. This decrement of 2.9% in test performance was produced by a mean COHb saturation of 9.74%.

The Effect of CO on 10-Second Estimations:

The effect of CO exposure upon the ability to estimate 10 seconds in the three test settings is presented in Table VIII which shows that no correlation exists between the ability to estimate 10 seconds and COHb saturations ranging from 0.4 - 20%. Regression analyses of the 10-second estimations showed a maximum correlation coefficient of -0.116, 0.229, and 0.190 for the group, isolated, and booth settings, respectively.

Comparison of the group and the individual baseline performance data versus performance data following CO exposure show no significant differences (Tables IV, V, VI and VII). The 95% confidence limits of the difference between the means of the estimation made by the non-exposed versus the exposed subjects, should it exist, is a maximum of 0.27 seconds (2.7%), 1.2 seconds (12%), and 0.67 seconds (6.7%) for the group, isolated, and booth settings, respectively.

The Effect of CO on 30-Second Estimations:

The effect of CO exposure upon the ability to estimate 30 seconds in the three test settings is presented in Table IX, which shows that no correlation exists between the ability to estimate 30 seconds and COHb saturations ranging from 0.4 - 20%. Regression analyses of the 30-second estimations showed a maximum correlation coefficient of 0.096, 0.20, and 0.31 for the group, isolated, and booth settings, respectively.

Comparison of the group baseline performance data versus performance following CO exposure (Tables IV, V, VI) did show a significant difference in the isolated setting while comparison of individual performance data (Table VII) failed to show a significant difference. The 95% confidence limits of the difference between the group means, should it exist, is a maximum of 0.58 seconds (1.9%), 4.06 seconds (13.3%), and 2.21 seconds (7.3%) for the group, isolated, and booth settings, respectively. These limits were inclusive of zero except for the alone setting which missed including zero by 0.37 seconds (1.2%).

The Effect of CO on the Marquette Time Estimation Test:

Three values were used to define test performance. The first two, the ratio of the estimate duration over the stimulus duration (E/S) and the absolute value of their difference $|E-S|$, were a measurement of the subject's ability to estimate the duration of the time stimulus. The third measurement was the subject's reaction time, that time from the end of the stimulus to the onset of the subject's response.

I. Estimate/Stimulus (E/S):

The relationships between the variable E/S and COHb saturation for the three stimulus lengths, two stimulus types and three test settings are presented in Tables X - XV. These data fail to indicate any relationship between performance and CO exposure. The maximum correlation coefficients from regression analysis are 0.189, 0.273, and 0.354 for the group, isolated, and booth settings, respectively.

Comparison of the baseline performance data versus exposure data using a group t-test (Tables XIV - XIX in reference 15) disclosed that the average E/S following CO exposure was higher ($p = .05$) for four of the eighteen combinations of stimulus durations, stimulus type and test setting. Analysis of the same data, individual by individual, using a paired t-test (Table VII), showed no significant difference between baseline performance and performance following CO exposure.

The 95% confidence limits of the average difference between the baseline performance and post-exposure performance data means for the three stimulus durations, two stimulus types and three test settings are presented in Tables XIV - XIX of reference 15. These limits were inclusive of zero in all but the four cases mentioned above. The maximum difference from zero within these limits was 0.07 (7%).

II. Absolute Value of Estimate-Stimulus ($|E-S|$):

The relationships between the variable ($|E-S|$) and COHb saturation for the three stimulus durations, two stimulus types and three test settings are presented in Tables XX - XXV of reference 15. There are no consistent trends and no relationship between performance and COHb saturation are evident. The maximum correlation coefficients from regression analysis are 0.120, 0.339, and 0.559 for the group, isolated and booth settings, respectively.

Comparison of the baseline performance data versus exposure data using a group t-test (Tables XXVI - XXXI in reference 15) revealed that the

average |E-S| following CO exposure was significantly different ($p = .05$) from baseline data in two of the eighteen combinations of stimulus durations, type and setting. Both of these cases occurred in the isolated setting where the subjects' time perception appeared to be improved by an elevated COHb saturation. Comparison of the same data, individual by individual, using a paired t-test (Table VII), revealed two of the sixteen combinations to be significantly ($p = .05$) different. These were two different combinations than mentioned above but, again, the subjects appeared to perform better with an elevated COHb saturation.

The 95% confidence limits on the difference between the means of the baseline performance data and post-exposure data for the various stimulus durations, types and test setting are presented in Tables XXVI - XXXI of reference 15. Only the two tests which were significantly different have limits not inclusive of zero and their maximum difference from zero is 0.03 (3%).

III. Reaction Time:

The relationships between the subjects' reaction time and COHb saturation for the three stimulus durations, two stimulus types and three test settings are presented in Tables XVI - XXI. It is apparent that there are no consistent trends in the data and that no relationship between reaction time and COHb saturation are present. The maximum correlation coefficients from regression analyses are 0.234, 0.344, and 0.431 for the group, isolated and booth settings, respectively.

Comparison of the baseline reaction times versus post-exposure reaction times using a group t-test (Tables XXXVIII - XLIII in reference 15) revealed that the average post-exposure reaction time was significantly different from the baseline reaction time in five of the eighteen combinations of stimulus durations, types and test settings. These differences occurred only in the group setting where the subjects had shorter reaction times with elevated COHb saturations. Comparison of the same data, individual by individual, using a paired t-test (Table VII) revealed no significant difference between baseline and post-exposure reaction times.

The 95% confidence limits of the difference between the means of the baseline and the post-exposure reaction times for the various stimulus lengths, types and test settings are presented in Tables XXXVIII - XLIII of reference 15. Only the five tests which were significantly different do not have limits inclusive of zero and their maximum difference from zero is 0.02 seconds.

DISCUSSION OF RESULTS

The results of these time perception studies indicate that the acute exposure of healthy adults to concentrations of CO up to 500 ppm which result in COHb saturations as great as 20% has no detrimental effect upon man's time sense. Thus, the studies corroborate the previously reported investigations of Stewart, et al[7], and O'Donnell, et al[8, 9]. The findings stand in obvious and striking disagreement to those reported by Beard and Wertheim[1, 2].

Beard-Wertheim Time Discrimination Tests:

The magnitude of the difference between the results of the Beard-Wertheim time discrimination test as performed in the two laboratories is graphically presented in Figure 1. The Beard-Wertheim data points represent the mean performance of a group of subjects individually tested in a single-blind mode in an audiometric booth. The data points from this laboratory show the mean performance of the 27 subjects tested in the five group settings in a double-blind mode. This immediately raises the question as to whether the observed difference could be significantly influenced by the test setting in which the investigations were conducted.

To evaluate the influence of interaction between individuals tested in a group setting upon time discrimination, nine individuals from the five groups were additionally tested in two isolated test settings: 1) in an audiometric booth identical in construction to that used by Beard and Wertheim; 2) when seated alone in the large environmental chamber. The results of this investigation are presented in Table XXII, which shows that there was no significant difference in the performance of the time discrimination test when administered in the three test settings.

The next possible reason for differences in test results may be that the time discrimination test sequences as performed in the two laboratories were not identical. At the present time there is no way to resolve this potential difference since the original Beard and Wertheim test tapes and raw data are no longer available for review. The original investigators neglected to

record the precise time intervals studied, however, the intervals studied in this laboratory (Table II) were chosen after consultation with Beard and Wertheim. Thus, the question as to the equality of the two tests may never be resolved.

Differences between the test populations could conceivably account for the differences in test results. Beard's subjects were Stanford University students who were paid $2.50 per hour. With the exception of the faculty members who participated in the study in this laboratory, the subjects were graduate students at Marquette University who were also paid $2.50 per hour. At this juncture there is no way to ascertain whether a significant difference in motivation existed between the two groups.

The next area which could have contributed to differences in test results between the two laboratories is that of the known technical differences in the testing procedure. These differences are listed in Table XXIII and most likely represent those factors most responsible for the test result differences. Finally, the failure to statistically evaluate each individual's performance by itself instead of lumping all data into group means precludes as complete analysis as is possible.

It was observed that in the group setting the subjects did not perform each of the three sequences in the Beard-Wertheim test with equal accuracy. These data are tabulated in Tables XLVI - XLVIII of reference 15. While the difference induced by the group setting is small, it is another test variable which could be of importance.

The test results revealed that no decrement in time discrimination occurred in subjects with elevated COHb saturation when tested in the isolated or in the group setting. However, in the booth setting, seven of the nine subjects had slight decrements in performance as determined by the paired t-test. This occurred at a mean COHb saturation of 9.74%. Unfortunately, the sample size of nine is not large enough to eliminate this as a spurious observation. Yet, even if this minute decrement were subsequently proved to occur in the booth test setting, the decrement of 0.74 correct responses out of 25 (2.9%) is still diametrically opposed to the decrement of 44% in test performance at this carboxyhemoglobin saturation which was reported by Beard and Wertheim.

In conclusion, the fact that two independent research groups utilizing a double-blind mode were unable to corroborate the gross time discrimination impairment reported by Beard and Wertheim, and that Dr. Beard himself could not reproduce his original observations when utilizing a double-blind mode, support the contention that carboxyhemoglobin saturations ranging from 0.4 tc 20% have no significant effect on the performance of the time discrimination test.

Ten Second Time Estimation:

The results of this study indicate that a COHb saturation ranging from 0.4 to 20% has no effect on the ability to estimate a ten-second interval. These results are in agreement with Beard and Wertheim [1,2] and O'Donnell,

et al [8, 9], who also reported no decrement in performance as a result of CO exposure.

It was observed, however, that the test setting in which this time estimation was performed did introduce a significant performance variable. These data are tabulated in Tables XLIX - LII of reference 15. The estimation of the ten-second interval in the group setting was significantly different than the estimation of the ten-second interval when in the isolated or in the booth test setting. This suggests that subject interaction may be responsible.

It is of interest to observe that in the group setting there was a significant difference in the estimated duration of each of the three 10-second intervals. Since this was observed in the group setting only, it suggests subject interaction and may well be explained by the fact that the signal switches were not completely silent and could be heard by others.

Thirty-Second Time Estimation:

The results of this study indicate that a COHb saturation ranging from 0.4 to 20% has no detrimental effect on the ability to estimate 30 seconds. This is in agreement with O'Donnell, et al [8, 9], but is in disagreement with Beard and Wertheim [1, 2]. The magnitude of the reported difference between the Beard-Wertheim data and that of this laboratory is shown in Figure 2.

As was the case with the 10-second time estimation testing, the test setting and not the COHb saturation was the significant variable responsible for the minute differences observed. These data are tabulated in Tables

LIV - LVI of reference 15. In the group test setting, the reproducibility of the estimation of one sequence to the next showed a slight but significant difference. The most likely explanation for this phenomenon is subject interaction in the group setting. Estimation of 30 seconds in the group and in the isolated setting did differ significantly from estimation of that time interval in the booth setting. This indicates that the use of an audiometric booth as a test chamber may allow the introduction of complex factors most difficult to define accurately.

Marquette Time Estimation Test:

While the Marquette time estimation test cannot be used to corroborate or disaffirm the Beard-Wertheim data, it can be used as a valid indicator of an individual's ability to rapidly estimate short intervals of time. The results of this study completely corroborate the results reported in a previous study [7] and clearly indicate that a COHb saturation ranging from 0.4 to 20% exerts no adverse effects upon the performance of this test.

There are additional interesting observations which can be made regarding the test and the performance differences which occurred in different test settings, performance differences completely unrelated to COHb saturations. Tables LVII - LXII in reference 15 show the influence of the test setting on the estimate/stimulus ratio. It is of interest to observe that the estimation of a short sound stimulus was influenced by the test setting while the estimation of the duration of a short light stimulus was not so influenced.

The estimation of the sound stimulus in the group setting was significantly different than when estimated in either the isolated or booth setting.

Tables LXIII - LXVIII in reference 15 reveal that the duration of the stimulus was a highly significant factor in accurately estimating its length. The one-second stimuli estimations were minutely, but significantly different for both sound and light stimuli duration in all three test settings.

Tables LXIX - LXXI in reference 15 reveal that in the group test setting, the subjects estimated the duration of short sound stimuli differently than the duration of short light stimuli.

Tables LXXII - LXXVII in reference 15 show the effect of the test setting upon the estimation of the stimulus as reflected in the variable $|E-S|$. In two of the eighteen testing situations, $|E-S|$ was significantly different but this was not additionally influenced by varying COHb saturations. Tables LXXVIII - LXXXIII of reference 15 again reflect the influence the duration of the stimulus had upon the accuracy of the response. The subjects handled the one-second stimuli significantly differently than the three and five-second stimuli. Only in the group test setting where subject interaction could occur did the type of stimulus presented influence the time estimation.

The subject's reaction time was longer in the group test setting than in the isolated or in the booth settings for stimuli of all durations and both types (Tables LXXXIV - LXXXIX in reference 15). The remainder of the tables in reference 15 show that the subjects' reaction time varied with the duration of the stimulus. It is apparent that each of the subjects used some method with

which to count and thereby estimate the duration of the stimulus. When the stimulus was not approximately one or three seconds, the subject would anticipate a stimulus of approximately five seconds and be better set to promptly react.

In conclusion it can be stated that while the Marquette time estimation test was influenced by multiple variables, it was not influenced by COHb saturation ranging from 0.4 - 20%.

SUMMARY

The purpose of this investigation was to study the effect of acute carbon monoxide exposure upon time perception with special attention to the Beard-Wertheim time discrimination test, the ten- and thirty-second time estimation tests, and the Marquette time estimation test. Twenty-seven healthy, adult male and female volunteers were exposed to carbon monoxide at concentrations of < 2, 50, 100, 200 and 500 ppm for periods up to $4\frac{1}{2}$ hours. The subjects were studied in three test settings: seated in small groups within the large environmental chamber, seated isolated in a large environmental chamber, and seated in an audiometric booth as had been done by Beard and Wertheim.

The results of the time perception studies can be summarized as follows:

1. The Beard-Wertheim time discrimination test was not affected by COHb saturations ranging from 0.4 - 20%. The test setting did not exert a significant affect upon the performance of this test.

2. The ability to estimate ten and thirty-second intervals was not affected by COHb saturations ranging from 0.4 to 20%. In the group setting, subject interaction did influence the test results.

3. The ability to perform the Marquette time estimation test was not affected by COHb saturations ranging from 0.4 to 20%. Time estimation was influenced by the type of stimulus, stimulus duration, and the test setting.

These results corroborate the previous studies by Stewart, et al, and O'Donnell, et al, dealing with the effect of acute CO exposure on time perception. The studies do not corroborate the reported findings of Beard and Wertheim. It appears that time perception is highly resistant to the effect of carbon monoxide and is unaffected by exposures which produce obvious toxic effects in more sensitive organ systems [7] and in people with advanced cardiovascular disease [16].

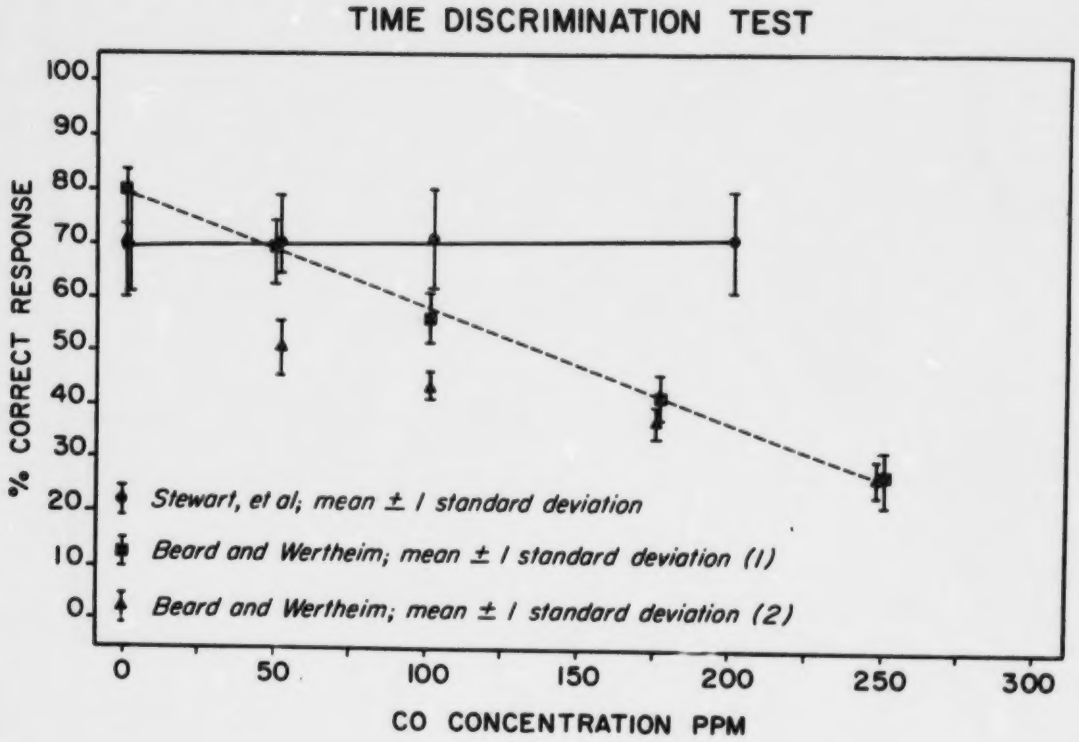
TIME DISCRIMINATION TEST
% CORRECT RESPONSE
100
90
80
70
60
50
40
30
20
10
0
Stewart, et al; mean ± 1 standard deviation
Beard and Wertheim; mean ± 1 standard deviation (1)
Beard and Wertheim; mean ± 1 standard deviation (2)
0
50
100
150
200
250
300
CO CONCENTRATION PPM

Figure 1

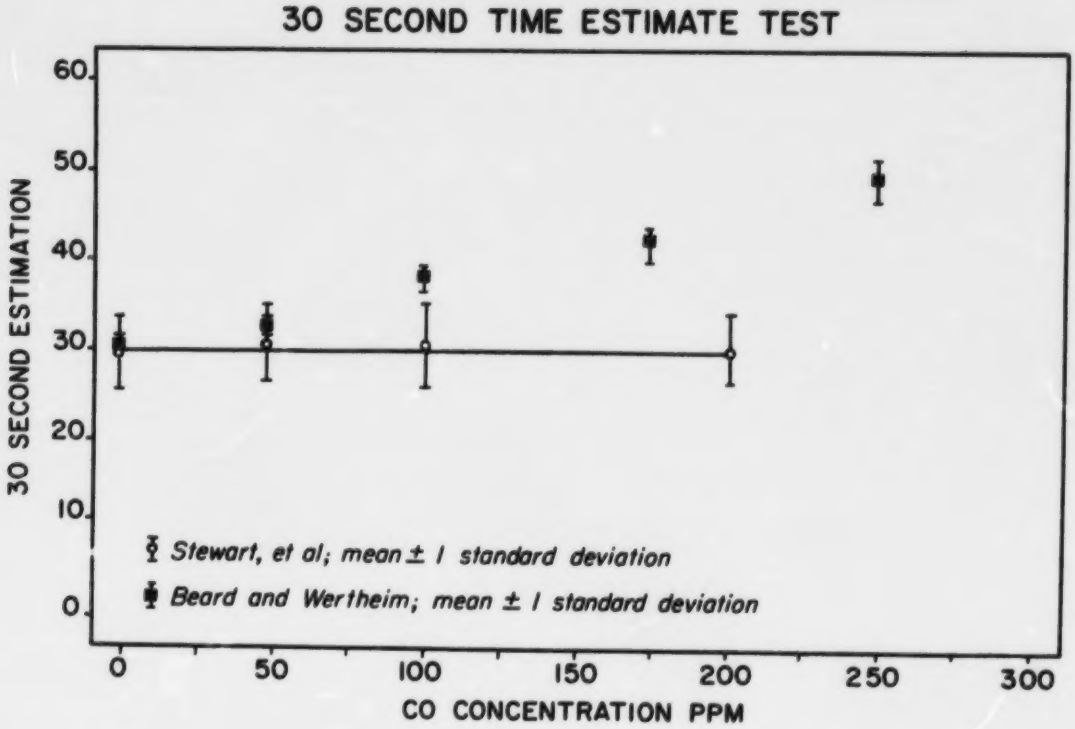
30 SECOND TIME ESTIMATE TEST
30 SECOND ESTIMATION
60
50
40
30
20
10
0
0
50
100
150
200
250
300
CO CONCENTRATION PPM
Stewart, et al; mean ± 1 standard deviation
Beard and Wertheim; mean ± 1 standard deviation

Figure 2

TABLE I

A CHRONOLOGICAL LISTING OF ALL EXPOSURES

Experiment	Subjects	CO Concentration, ppm			Duration (hr)
		Mean	S. D.	S. E.	
1	8	100.99	4.28	0.54	5.0
2	8	50.64	3.83	0.54	5.0
3	8	196.49	3.00	0.41	5.0
4	8	< 2	- -	- -	5.0
5	8	49.82	2.36	0.31	5.0
6	7	201.38	6.58	0.95	5.0
7	6	< 2	- -	- -	5.0
8	7	99.81	3.77	0.77	2.5
9	8	96.13	4.39	0.62	5.0
10	6	203.69	6.39	1.33	2.5
11	8	< 2	- -	- -	5.0
12	6	< 2	- -	- -	2.5
13	6	49.45	1.43	0.27	2.5
14	6	201.70	4.21	0.72	2.5
15	6	< 2	- -	- -	2.5
16	6	49.67	3.56	0.66	2.5
17	4	99.93	1.66	0.31	2.5
18	2	201.72	6.94	1.36	2.5
19	1	192.90	5.85	1.15	2.5
20	2	< 2	- -	- -	2.5
21	2	< 2	- -	- -	2.5
22	2	< 2	- -	- -	2.5
23	6	< 2	- -	- -	5.0
24	2	193.10	13.40	2.60	2.5
25	2	197.70	9.56	1.69	2.5
26	2	< 2	- -	- -	2.5
27	6	192.30	21.40	3.50	5.0
28	2	199.96	2.97	0.56	2.5
29	2	< 2	- -	- -	2.5
30	2	< 2	- -	- -	2.5
31	5	190.00	17.50	2.50	2.5
32	5	196.98	8.66	1.69	5.0
33	6	< 2	- -	- -	5.0
34	1	< 2	- -	- -	2.5
35	2	< 2	- -	- -	2.5

Table I, continued

36	1	< 2	- -	- -	2.5
37	7	198.61	6.47	0.55	5.0
38	7	< 2	- -	- -	5.0
39	7	210.08	13.66	1.17	5.0
40	7	199.21	10.12	0.87	5.0
41	6	< 2	- -	- -	5.0
42	7	< 2	- -	- -	5.0
43	7	197.80	6.06	0.53	5.0
44	6	2.87	0.99	0.86	5.0
45	6	< 2	- -	- -	5.0
46	7	197.48	6.49	0.55	5.0
47	8	203.40	10.12	0.81	5.0
48	8	507.00	9.06	1.49	
49	8	500 ppm for 75 minutes, then 100 ppm for 140 minutes			
50	8	< 2	- -	- -	5.0

TABLE II

The Beard-Wertheim test was composed of three sequences with a few seconds rest between each sequence. Each sequence was composed of twenty-five pairs of tones. The first tone was always one second in duration, and was followed 0.5 seconds later by a second tone of identical, slightly longer or slightly shorter duration. The length of the second tone for each pair was as follows:

Sequence I	Sequence II	Sequence III
1240 msec.	880 msec.	1160 msec.
1080	840	1000
880	640	1000
1000	1200	1120
760	1320	1000
840	1000	800
1000	1280	1000
1200	1080	720
1320	1000	920
640	800	1040
1000	1000	960
680	680	640
960	720	1240
1000	960	1080
800	1000	1200
720	920	680
1120	1000	1000
1040	1240	760
920	1000	880
1160	1120	1000
1280	1040	1000
1000	1000	1320
1000	1160	1280
1000	1000	840
1000	760	1000

TABLE III

RELATIONSHIP BETWEEN PERFORMANCE
OF THE BEARD-WERTHEIM TIME DISCRIMINATION TEST
AND CARBOXYHEMOGLOBIN SATURATION

Situation	PERCENT CARBOXYHEMOGLOBIN LEVEL EXPOSURE DATA							
	Baseline Data	0 - 2	2.01 - 4	4.01 - 8	8.01 - 12	12.01 - 16	16.01 - 20	0 - 20
Group	17.73±2.26* N = 395	17.67±2.52 N = 18	17.66±1.97 N = 111	17.55±2.25 N = 212	17.77±2.27 N = 185	17.23±2.37 N = 166	17.56±2.26 N = 114	17.55±2.25 N = 806
Alone	17.67±2.73 N = 42	N = 0	N = 0	17.83±2.12 N = 12	18.00±2.65 N = 15	N = 0	N = 0	17.92±2.38 N = 27
Booth	18.02±2.39 N = 59	N = 0	N = 0	16.33±3.51 N = 3	18.38±1.75 N = 21	16.67±1.53 N = 3	N = 0	17.96±2.03 N = 27

* Mean ± 1 Standard Deviation

TABLE IV

COMPARISON OF BASELINE AND EXPOSURE DATA FOR THE

10 AND 30 SECOND ESTIMATIONS AND THE BEARD-WERTHEIM TEST

GROUP SITUATION	Baseline Data	Exposure Data	F and t Test Values	95% Confidence Limits of D*
10 Second Estimations	9.85±1.53** N = 591	9.98±1.41 N = 1194	F = 1.085 t = 1.782	$-0.016 \leq D \leq 0.278$
30 Second Estimations	30.44±4.29 N = 576	30.58±4.27 N = 1175	F = 1.005 t = 0.644	$-0.283 \leq D \leq 0.575$
Beard Test	17.73±2.26 N = 395	17.55±2.25 N = 806	F = 1.004 t = 1.301	$-0.445 \leq D \leq 0.101$

* Average Difference Between Group Means

** Mean ± 1 Standard Deviation

TABLE V

COMPARISON OF BASELINE AND EXPOSURE DATA FOR THE

10 AND 30 SECOND ESTIMATIONS AND THE BEARD-WERTHEIM TEST

ALONE SITUATION	Baseline Data	Exposure Data	F and t Test Values	95% Confidence Limits of D*
10 Second Estimations	10.07 ± 1.89** N = 57	10.48 ± 2.15 N = 46	F = 1.138 t = 1.029	-0.393 ≤ D ≤ 1.205
30 Second Estimations	30.38 ± 4.08 N = 52	32.60 ± 5.03 N = 46	F = 1.236 t = 2.413+	+0.369 ≤ D ≤ 4.061
Beard Test	17.67 ± 2.73 N = 42	17.92 ± 2.38 N = 27	F = 1.147 t = 0.390	-0.982 ≤ D ≤ 1.50

* Average Difference Between Group Means
** Mean ± 1 Standard Deviation
\+ Significant at the 95% level
++ Significant at the 99% level

TABLE VI

COMPARISON OF BASELINE AND EXPOSURE DATA FOR THE

10 AND 30 SECOND ESTIMATIONS AND THE BEARD-WERTHEIM TEST

BOOTH SITUATION	Baseline Data	Exposure Data	F and t Test Values	95% Confidence Limits of D*
10 Second Estimations	10.36 $\pm$ 1.56** N = 84	10.42 $\pm$ 1.84 N = 50	F = 1.180 t = 0.201	$-0.556 \leq D \leq 0.674$
30 Second Estimations	32.02 $\pm$ 3.63 N = 83	32.83 $\pm$ 4.17 N = 51	F = 1.149 t = 1.185	$-0.594 \leq D \leq 2.206$
Beard Test	18.02 $\pm$ 2.39 N = 59	17.96 $\pm$ 2.03 N = 27	F = 1.177 t = 0.113	$-1.047 \leq D \leq 0.939$

* Average Difference Between Group Means

** Mean $\pm$ 1 Standard Deviation

TABLE VII

PAIRED "t" VALUES FOR TIME DISCRIMINATION TESTS

TEST		GROUP SITUATION		ALONE SITUATION		BOOTH SITUATION	
Marquette Test		t	df	t	df	t	df
One Second Sound	E/S	-1.59	26	-0.48	4	-0.65	8
	|E-S|	-0.06	26	0.16	4	-0.29	8
	RxT	0.54	26	2.40	4	0.92	8
Three Second Sound	E/S	1.23	26	0.13	4	0.06	8
	|E-S|	-0.45	26	2.70	4	1.32	8
	RxT	0.66	26	1.00	4	-1.20	7
Five Second Sound	E/S	0.92	26	0.54	4	0.57	8
	|E-S|	-0.03	26	0.90	4	0.46	8
	RxT	0.30	25	1.26	4	0.91	8
One Second Light	E/S	-0.25	26	-0.34	4	0.59	8
	|E-S|	1.16	26	3.87*	4	2.65*	8
	RxT	0.35	26	1.48	4	1.02	8
Three Second Light	E/S	-0.96	26	-0.04	4	-0.37	8
	|E-S|	1.94	26	1.16	4	0.01	8
	RxT	0.85	26	1.04	4	-0.74	8
Five Second Light	E/S	0.81	26	0.85	4	0.97	8
	|E-S|	0.06	26	1.74	4	-0.24	8
	RxT	0.88	26	0.60	4	0.86	8
10 Second Estimation		0.20	26	0.32	4	-0.30	8
30 Second Estimation		-0.93	26	0.25	4	-0.32	8
Bernard Test		0.66	23	-1.32	4	2.75*	8

* Significant at 95% level
** Significant at 99% level

TABLE VIII

RELATIONSHIP OF 10 SECOND ESTIMATIONS TO

CARBOXYHEMOGLOBIN SATURATION

Situation	PERCENT CARBOXYHEMOGLOBIN LEVEL EXPOSURE DATA							
	Baseline Data	0 - 2	2.01 - 4	4.01 - 8	8.01 - 12	12.01 - 16	16.01 - 20	0 - 20
Group	9.85 ± 1.53 * N = 591	10.14±1.67 N = 399	9.99±1.22 N = 123	9.91±1.15 N = 209	10.01±1.32 N = 183	9.80± 1.29 N = 166	9.75±1.28 N = 114	9.98 ± 1.41 N = 1194
Alone	10.07±1.89 N = 57	10.26±1.99 N = 18	N = 0	10.65±2.32 N = 13	10.59±2.30 N = 15	N = 0	N = 0	10.48±2.15 N = 46
Booth	10.36±1.56 N = 84	10.40±1.60 N = 27	N = 0	10.90±0.69 N = 3	10.12±2.37 N = 17	11.87±.49 N = 3	N = 0	10.42±1.84 N = 50

* Mean ± 1 Standard Deviation

TABLE IX

RELATIONSHIP OF 30 SECOND ESTIMATIONS

TO CARBOXYHEMOGLOBIN SATURATION

Situation	PERCENT CARBOXYHEMOGLOBIN LEVEL EXPOSURE DATA							
	Baseline Data	0 - 2	2.01 - 4	4.01 - 8	8.01 - 12	12.01 - 16	16.01 - 20	0 - 20
Group	30.44±4.29* N = 576	31.07±4.71 N = 393	30.41±4.11 N = 122	30.57±4.04 N = 208	31.11±4.03 N = 178	29.92±4.03 N = 162	29.20±3.53 N = 112	30.58±4.27 N = 1175
Alone	30.38±4.07 N = 52	32.16±4.37 N = 17	N = 0	33.99±5.15 N = 14	31.79±5.66 N = 15	N = 0	N = 0	32.60±5.03 N = 46
Booth	32.02±3.63 N = 83	32.57±4.31 N = 27	N = 0	32.57±0.40 N = 3	32.48±4.31 N = 18	37.50±1.15 N = 3	N = 0	32.83±4.17 N = 51

* Mean ± 1 Standard Deviation

TABLE X

RELATIONSHIP BETWEEN PERFORMANCE OF THE
MARQUETTE TIME TEST AND CARBOXYHEMOGLOBIN SATURATION
1 SECOND SOUND - ESTIMATE/STIMULUS

Situation	PERCENT CARBOXYHEMOGLOBIN LEVEL EXPOSURE DATA							
	Baseline Data	0 - 2	2.01 - 4	4.01 - 8	8.01 - 12	12.01 - 16	16.01 - 20	0 - 20
Group	1.03 ± 0.25* N = 392	1.26 ± .23 N = 16	1.19 ± .24 N = 105	1.17 ± .23 N = 200	1.13 ± .24 N = 162	1.07 ± .26 N = 158	1.06 ± .22 N = 111	1.13 ± .25 N = 752
Alone	0.94 ± .23 N = 42	N = 0	N = 0	0.88 ± .24 N = 15	0.97 ± .28 N = 15	N = 0	N = 0	0.92 ± .26 N = 30
Booth	0.94 ± .21 N = 60	N = 0	N = 0	1.14 ± .07 N = 3	0.99 ± .27 N = 21	0.78 ± .10 N = 3	N = 0	0.98 ± .26 N = 27

* Mean ± 1 Standard Deviation

TABLE XI

RELATIONSHIP BETWEEN PERFORMANCE OF THE
MARQUETTE TIME TEST AND CARBOXYHEMOGLOBIN SATURATION
3 SECOND SOUND - ESTIMATE/STIMULUS

Situation	PERCENT CARBOXYHEMOGLOBIN LEVEL EXPOSURE DATA							
	Baseline Data	0 - 2	2.01 - 4	4.01 - 8	8.01 - 12	12.01 - 16	16.01 - 20	0 - 20
Group	1.08 ± .17 * N = 399	1.02 ± .24 N = 17	1.07 ± .21 N = 108	1.09 ± .17 N = 202	1.09 ± .17 N = 166	1.09 ± .19 N = 153	1.08 ± .19 N = 108	1.09 ± .18 N = 754
Alone	0.99 ± .14 N = 39	N = 0	N = 0	0.96 ± .10 N = 15	0.96 ± .09 N = 15	N = 0	N = 0	0.96 ± .09 N = 30
Booth	1.00 ± .16 N = 58	N = 0	N = 0	1.12 ± .16 N = 3	0.96 ± .12 N = 21	0.95 ± .06 N = 2	N = 0	0.98 ± .13 N = 26

* Mean ± 1 Standard Deviation

TABLE XII

RELATIONSHIP BETWEEN PERFORMANCE OF THE
MARQUETTE TIME TEST AND CARBOXYHEMOGLOBIN SATURATION
5 SECOND SOUND - ESTIMATE/STIMULUS

Situation	PERCENT CARBOXYHEMOGLOBIN LEVEL EXPOSURE DATA							
	Baseline Data	0 - 2	2.01 - 4	4.01 - 8	8.01 - 12	12.01 - 16	16.01 - 20	0 - 20
Group	1.03 ± .13* N = 397	1.01 ± .11 N = 17	1.03 ± .14 N = 106	1.05 ± .13 N = 184	1.07 ± .13 N = 167	1.06 ± .15 N = 160	1.05 ± .13 N = 113	1.05 ± .13 N = 747
Alone	1.01 ± .10 N = 40	N = 0	N = 0	0.95 ± .09 N = 15	0.97 ± .10 N = 15	N = 0	N = 0	0.96 ± .09 N = 30
Booth	0.96 ± .10 N = 58	N = 0	N = 0	0.98 ± .05 N = 3	0.96 ± .11 N = 20	0.95 ± .01 N = 3	N = 0	0.96 ± .10 N = 26

* Mean ± 1 Standard Deviation

TABLE XIII

RELATIONSHIP BETWEEN PERFORMANCE OF THE
MARQUETTE TIME TEST AND CARBOXYHEMOGLOBIN SATURATION
1 SECOND LIGHT - ESTIMATE/STIMULUS

Situation	PERCENT CARBOXYHEMOGLOBIN LEVEL EXPOSURE DATA							
	Baseline Data	0 - 2	2.01 - 4	4.01 - 8	8.01 - 12	12.01 - 16	16.01 - 20	0 - 20
Group	1.00 ± .26 * N = 362	1.21 ± .17 N = 17	1.14 ± .26 N = 110	1.11 ± .23 N = 198	1.07 ± .25 N = 181	1.02 ± .25 N = 163	1.01 ± .24 N = 114	1.07 ± .25 N = 783
Alone	0.95 ± .28 N = 42	N = 0	N = 0	0.90 ± .22 N = 15	0.90 ± .29 N = 15	N = 0	N = 0	0.90 ± .25 N = 30
Booth	0.96 ± .24 N = 60	N = 0	N = 0	0.91 ± .10 N = 3	0.97 ± .17 N = 21	0.70 ± .13 N = 3	N = 0	0.93 ± .18 N = 27

* Mean ± 1 Standard Deviation

TABLE XIV

RELATIONSHIP BETWEEN PERFORMANCE OF THE
MARQUETTE TIME TEST AND CARBOXYHEMOGLOBIN SATURATION
3 SECOND LIGHT - ESTIMATE/STIMULUS

Situation	PERCENT CARBOXYHEMOGLOBIN LEVEL EXPOSURE DATA							
	Baseline Data	0 - 2	2.01 - 4	4.01 - 8	8.01 - 12	12.01 - 16	16.01 - 20	0 - 20
Group	1.00 ± .15* N = 366	1.03 ± .14 N = 18	1.00 ± .13 N = 108	1.02 ± .12 N = 197	1.03 ± .13 N = 179	0.99 ± .14 N = 163	1.01 ± .14 N = 114	1.01 ± .13 N = 779
Alone	0.96 ± .15 N = 42	N = 0	N = 0	0.94 ± .10 N = 15	0.94 ± .17 N = 15	N = 0	N = 0	0.94 ± .13 N = 30
Booth	0.97 ± .14 N = 57	N = 0	N = 0	1.01 ± .12 N = 3	0.98 ± .15 N = 21	0.94 ± .04 N = 3	N = 0	0.97 ± .14 N = 27

* Mean ± 1 Standard Deviation

TABLE XV

RELATIONSHIP BETWEEN PERFORMANCE OF THE
MARQUETTE TIME TEST AND CARBOXYHEMOGLOBIN SATURATION
5 SECOND LIGHT - ESTIMATE/STIMULUS

Situation	PERCENT CARBOXYHEMOGLOBIN LEVEL EXPOSURE DATA							
	Baseline Data	0 - 2	2.01 - 4	4.01 - 8	8.01 - 12	12.01 - 16	16.01 - 20	0 - 20
Group	0.99 ± .13 * N = 364	0.98 ± .06 N = 18	1.00 ± .10 N = 103	1.01 ± .10 N = 205	1.02 ± .11 N = 180	1.01 ± .13 N = 159	1.02 ± .13 N = 112	1.01 ± .11 N = 777
Alone	0.98 ± .13 N = 40	N = 0	N = 0	0.94 ± .12 N = 15	0.96 ± .13 N = 15	N = 0	N = 0	0.95 ± .12 N = 30
Booth	0.98 ± .11 N = 59	N = 0	N = 0	0.95 ± .07 N = 3	0.96 ± .12 N = 21	0.83 ± .10 N = 3	N = 0	0.94 ± .12 N = 27

* Mean ± 1 Standard Deviation

TABLE XVI

RELATIONSHIP BETWEEN PERFORMANCE OF THE
MARQUETTE TEST AND CARBOXYHEMOGLOBIN SATURATION

1 SECOND SOUND - REACTION TIME

Situation	PERCENT CARBOXYHEMOGLOBIN LEVEL EXPOSURE DATA							
	Baseline Data	0 - 2	2.01 - 4	4.01 - 8	8.01 - 12	12.01 - 16	16.01 - 20	0 - 20
Group	0.32 ± .13* N = 391	0.24 ± .10 N = 18	0.29 ± .12 N = 110	0.29 ± .13 N = 201	0.30 ± .14 N = 162	0.33 ± .13 N = 152	0.36 ± .13 N = 110	0.31 ± .13 N = 753
Alone	0.24 ± .16 N = 42	N = 0	N = 0	0.26 ± .13 N = 15	0.20 ± .13 N = 14	N = 0	N = 0	0.23 ± .13 N = 29
Booth	0.23 ± .10 N = 59	N = 0	N = 0	0.05 ± .04 N = 3	0.24 ± .12 N = 19	0.25 ± .13 N = 3	N = 0	0.22 ± .13 N = 25

* Mean ± 1 Standard Deviation

TABLE XVII

RELATIONSHIP BETWEEN PERFORMANCE OF THE
MARQUETTE TEST AND CARBOXYHEMOGLOBIN SATURATION

3 SECOND SOUND - REACTION TIME

Situation	PERCENT CARBOXYHEMOGLOBIN LEVEL EXPOSURE DATA							
	Baseline Data	0 - 2	2.01 - 4	4.01 - 8	8.01 - 12	12.01 - 16	16.01 - 20	0 - 20
Group	0.30 ± .12* N = 392	0.23 ± .08 N = 18	0.27 ± .10 N = 110	0.27 ± .12 N = 201	0.27 ± .11 N = 164	0.30 ± .12 N = 153	0.32 ± .12 N = 112	0.28 ± .12 N = 758
Alone	0.28 ± .16 N = 41	N = 0	N = 0	0.28 ± .18 N = 15	0.22 ± .13 N = 14	N = 0	N = 0	0.25 ± .16 N = 29
Booth	0.21 ± .08 N = 54	N = 0	N = 0	0.13 ± .10 N = 3	0.21 ± .11 N = 17	0.27 ± .04 N = 2	N = 0	0.20 ± .10 N = 22

* Mean ± 1 Standard Deviation

TABLE XVIII

RELATIONSHIP BETWEEN PERFORMANCE OF THE

MARQUETTE TEST AND CARBOXYHEMOGLOBIN SATURATION

5 SECOND SOUND - REACTION TIME

Situation	PERCENT CARBOXYHEMOGLOBIN LEVEL EXPOSURE DATA							
	Baseline Data	0 - 2	2.01 - 4	4.01 - 8	8.01 - 12	12.01 - 16	16.01 - 20	0 - 20
Group	0.26 ± .11* N = 396	0.17 ± .06 N = 18	0.21 ± .10 N = 111	0.23 ± .11 N = 182	0.23 ± .09 N = 164	0.26 ± .10 N = 160	0.27 ± .09 N = 112	0.24 ± .10 N = 747
Alone	0.18 ± .12 N = 39	N = 0	N = 0	0.21 ± .10 N = 15	0.14 ± .13 N = 15	N = 0	N = 0	0.17 ± .12 N = 30
Booth	0.19 ± .12 N = 58	N = 0	N = 0	0.06 ± .05 N = 3	0.21 ± .13 N = 16	0.15 ± .07 N = 3	N = 0	0.18 ± .12 N = 22

* Mean ± 1 Standard Deviation

TABLE XIX

RELATIONSHIP BETWEEN PERFORMANCE OF THE
MARQUETTE TEST AND CARBOXYHEMOGLOBIN SATURATION

1 SECOND LIGHT - REACTION TIME

Situation	PERCENT CARBOXYHEMOGLOBIN LEVEL EXPOSURE DATA							
	Baseline Data	0 - 2	2.01 - 4	4.01 - 8	8.01 - 12	12.01 - 16	16.01 - 20	0 - 20
Group	0.30 ± .11* N = 353	0.21 ± .06 N = 17	0.27 ± .11 N = 108	0.27 ± .11 N = 200	0.27 ± .10 N = 173	0.30 ± .11 N = 161	0.34 ± .11 N = 114	0.28 ± .11 N = 773
Alone	0.24 ± .13 N = 39	N = 0	N = 0	0.23 ± .11 N = 15	0.22 ± .09 N = 15	N = 0	N = 0	0.23 ± .10 N = 30
Booth	0.21 ± .10 N = 54	N = 0	N = 0	0.08 ± .03 N = 3	0.19 ± .11 N = 21	0.24 ± .03 N = 3	N = 0	0.18 ± .11 N = 27

* Mean ± 1 Standard Deviation

TABLE XX

RELATIONSHIP BETWEEN PERFORMANCE OF THE

MARQUETTE TEST AND CARBOXYHEMOGLOBIN SATURATION

3 SECOND LIGHT - REACTION TIME

Situation	PERCENT CARBOXYHEMOGLOBIN LEVEL EXPOSURE DATA							
	Baseline Data	0 - 2	2.01 - 4	4.01 - 8	8.01 - 12	12.01 - 16	16.01 - 20	0 - 20
Group	0.27 ± .10* N = 360	0.19 ± .07 N = 18	0.24 ± .08 N = 107	0.24 ± .08 N = 193	0.26 ± .09 N = 179	0.27 ± .09 N = 158	0.29 ± .08 N = 107	0.26 ± .09 N = 762
Alone	0.22 ± .13 N = 42	N = 0	N = 0	0.28 ± .18 N = 15	0.18 ± .09 N = 15	N = 0	N = 0	0.23 ± .14 N = 30
Booth	0.21 ± .07 N = 54	N = 0	N = 0	0.16 ± .11 N = 3	0.19 ± .07 N = 18	0.29 ± .07 N = 3	N = 0	0.20 ± .08 N = 24

* Mean ± 1 Standard Deviation

TABLE XXI

RELATIONSHIP BETWEEN PERFORMANCE OF THE

MARQUETTE TEST AND CARBOXYHEMOGLOBIN SATURATION

5 SECOND LIGHT - REACTION TIME

Situation	PERCENT CARBOXYHEMOGLOBIN LEVEL EXPOSURE DATA							
	Baseline Data	0 - 2	2.01 - 4	4.01 - 8	8.01 - 12	12.01 - 16	16.01 - 20	0 - 20
Group	0.26 ± .11* N = 370	0.16 ± .05 N = 18	0.18 ± .07 N = 109	0.20 ± .07 N = 204	0.23 ± .08 N = 173	0.25 ± .11 N = 163	0.28 ± .11 N = 114	0.23 ± .09 N = 781
Alone	0.19 ± .14 N = 36	N = 0	N = 0	0.22 ± .15 N = 15	0.15 ± .11 N = 14	N = 0	N = 0	0.18 ± .13 N = 29
Booth	0.18 ± .10 N = 58	N = 0	N = 0	0.05 ± .01 N = 3	0.18 ± .13 N = 18	0.23 ± .05 N = 3	N = 0	0.17 ± .12 N = 24

* Mean ± 1 Standard Deviation

TABLE XXII

COMPARISON OF TESTING SITUATIONS

BEARD TEST		BEARD TEST: BOOTH	BEARD TEST: ALONE	BEARD TEST: GROUP
BEARD TEST	GROUP $17.73 \pm 2.26^{***}$; N = 395	F = 1.056 t = .9115	F = 1.210 t = .160	----
	ALONE $17.67 \pm 2.74^{***}$; N = 42	F = 1.146 t = .683	----	
	BOOTH $18.02 \pm 2.39^{***}$; N = 59	----		

* Significant at the .95 level
** Significant at the .99 level
*** Mean $\pm$ 1 Standard Deviation
Note: Only baseline data used for this analysis

Reproduced from best available copy.

TABLE XXIII

COMPARISON OF TECHNICAL PROCEDURES USED

BY TWO LABORATORIES PERFORMING TIME DISCRIMINATION TESTS

Procedure	Beard-Wertheim	Stewart, et al
Experimental Protocol	Single-Blind	Double-Blind
Chamber CO Monitoring System	Single infrared instrument; calibration standards not run from within chamber. CO concentration mean and standard deviation not reported.	Three, independent monitoring systems; calibration standards run every hour from within the chamber. CO concentration mean and standard deviation reported.
COHb Determinations	Blood obtained, results not reported. COHb estimated from breath samples in one of two studies.	Hourly COHb determinations made by two independent methods.
Test Populations	Stanford University students	Marquette University graduate students and Medical School faculty.
Test Setting	Audiometric Booth	3 settings: audiometric booth, subject isolated in large room, subjects tested in small groups.

REFERENCES

1. Beard, R. R., and Wertheim, G. A.: Behavioral Impairment Associated with Small Doses of Carbon Monoxide. Amer. J. Public Health. 57:2012-2022, 1967.
2. Beard, R. R., and Wertheim, G. A.: Behavioral Manifestations of Carbon Monoxide Absorption: Presented at the XVI International Congress on Occupational Health, Tokyo, September 25, 1969.
3. Threshold Limit Values for Substances in Workroom Air Adopted by ACGIH for 1972. American Conference of Governmental Industrial Hygienists. Cincinnati, 1972.
4. Research Study to Determine the Range of Carboxyhemoglobin in Various Segments of the American Population: Annual report for October 1, 1970 - September 30, 1971, to the Coordinating Research Council and the Environmental Protection Agency by the Department of Environmental Medicine, The Medical College of Wisconsin; Report No.: CRC APRAC CAPM-8-68 MCOW-ENVM-COHb-71-1.
5. Effects of Chronic Exposure to Low Levels of Carbon Monoxide on Human Health Behavior, and Performance: National Academy of Sciences and National Academy of Engineering, Standard Book No. 309-01735-1.
6. The Health Consequences of Smoking: A Report of the Surgeon General, 1972. U. S. Department of Health, Education and Welfare; Public Health Service, 1972.

7. Stewart, R. D., Peterson, J. E., Baretta, E. D., Bachand, R. T., Hosko, M. J., and Herrmann, A. A.: Experimental Human Exposure to Carbon Monoxide. Arch. of Environ. Health, 21:154-164, 1970.

8. O'Donnell, R. D., Mikulka, P., Heinig, P., and Theodore, J.: Low Level Carbon Monoxide Exposure and Human Psychomotor Performance. Toxicol. Appl. Pharmacol. 18:593-602, 1971.

9. O'Donnell, R. D., Chikos, P., and Theodore, J.: Effect of Carbon Monoxide Exposure on Human Sleep and Psychomotor Performance. J. Appl. Physiol. 31:513-518, 1971.

10. Bartlett, D.: Pathophysiology of Exposure to Low Concentrations of Carbon Monoxide. Arch. Environ. Health. 16:719-727, 1968.

11. Air Quality Criteria for Carbon Monoxide: U. S. Department of Health, Education and Welfare; National Air Pollution Control Administration Publication, No. AP-62.

12. Dinman, B. D.: Pathophysiologic Determinants of Community Air Quality Standards for Carbon Monoxide. J. Occup. Med. 10:446-456, 1968.

13. Beard, R. R.: First Annual Conference on Environmental Toxicology, 9-11 September 1970. Statement made to the audience of scientists during the discussion of his paper.

14. Stewart, R. D.: Use of Human Volunteers for the Toxicological Evaluation of Materials. Symposium on An Appraisal of Halogenated Fire Extinguishing Agents. National Academy of Sciences, Washington, D. C.

15. Stewart, R. D., Newton, P. E., Hosko, M. J., and Peterson, J. E.: The Effect of Carbon Monoxide on Time Perception. Report No.: CRC APRAC CAPM-3-68 MCOW-ENVM-CO-72-1. Available at the National Clearing House.

16. Aronow, W. S., Harris, C. N., Isbell, M. W., Rokaw, S. N., and Imparato, B.: Effect of Freeway Travel on Angina Pectoris. Annals of Int. Med. 77:669-676, 1972.